

## **AC 2010-1535: FROM CORNERSTONE TO CAPSTONE: SYSTEMS ENGINEERING THE WEST POINT WAY**

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# **From Cornerstone to Capstone: Systems Engineering the West Point Way**

## **Abstract**

The United States Military Academy at West Point was established in 1802 and is the nation's oldest engineering school. West Point is a four-year undergraduate institution that confers bachelor of sciences degrees on all of its graduates who then enter active military service as commissioned Army officers. West Point offers majors programs in several different engineering disciplines as well as in the humanities and social sciences. In 1989 West Point established a Department of Systems Engineering, which administers the Systems Engineering major among other related disciplines. The Systems Engineering program has been accredited by the Engineering Accreditation Commission (EAC) of ABET since 1996.

The foundation of the Systems Engineering major at West Point is the Systems Decision Process (SDP). The SDP serves as the overarching engineering thought and design process for the program. Systems thinking and decision making concepts are emphasized in the SDP because our graduates will soon be US Army officers responsible for life and death decisions at a young age. There are four phases to the SDP: Problem Definition, Solution Design, Decision Making, and Solution Implementation. Each phase consists of three key tasks. The SDP is a holistic engineering design process that explicitly considers the many environmental factors that impact the systems being engineered.

The West Point systems engineering undergraduate major is designed to teach and reinforce the SDP. The cornerstone of this program is the introductory course where the students are introduced to the SDP thereby laying the foundation for the rest of the curriculum. Building upon this foundation, the program layers a series of courses that cover basic engineering principles as well as courses that provide the basic tools and methods used by Systems Engineers. Each student also studies a sub-discipline to provide depth in one of a number of areas including human factors, mathematical sciences, simulation studies and information systems.

All Systems Engineering majors at West Point complete their undergraduate education with a year-long design course in which they design a system to solve a real-world problem for a real-world client typically within the Department of Defense. In this capstone experience the students are asked to integrate and use the many tools and techniques they have learned throughout their academic experience at West Point, to include their robust background in humanities and social sciences.

In total, the Systems Engineering curriculum at West Point is designed to provide students with a multi-disciplinary and systems perspective on engineering and decision-making while engaging them in solving real problems for real clients. The West Point Systems Engineering major is one of the few ABET-accredited undergraduate systems engineering programs in the nation and it prepares students well for the uncertain and complex world in which they will live.

**Disclaimer.** The views expressed in this article are those of the authors, and/ or presenters at the conference, and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the U.S. Government.

## **The West Point Academic Program**

West Point was established by President Jefferson in 1802 as a place to educate officers for the US Army. This served two primary purposes: to develop a professional officer corps for the US Army and to educate engineers who could develop the infrastructure of our fledgling nation. President George Washington first proposed the idea of establishing a national military academy however he was unable to get it approved while in office. Secretary of War James McHenry wrote in the New York Spectator paper on February 22, 1800 that “George Washington urged a Military Academy for years. During the War he said he had ‘an Army of men, but few (real) Officers or Soldiers in that Army; Time and Instructors are required – to enable the Army, to meet the enemy upon anything like Equal Terms.’ The Officers are to be instructed in moral, mechanical, geometrical and physical rules.”<sup>1</sup> Over the years the curriculum has changed dramatically however our mission of educating officers for the US Army has remained the central focus of what we do. The current mission of West Point is:

"To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country and prepared for a career of professional excellence and service to the Nation as an officer in the United States Army."<sup>2</sup>

The totality of the West Point leader development curriculum is considered to be a 47-month experience in which students (cadets) must adequately achieve outcomes in six developmental domains, which are implemented in the academic, physical and military programs. The goals and outcomes that cadets are expected to achieve in these six domains are codified in the Cadet Leader Development System, which provides the framework for developing, implementing and assessing the overall curriculum.<sup>3</sup> Upon successful completion of the programs in these domains cadets graduate with a bachelor of sciences degree and receive a commission as an officer in the United States Army. The United States Military Academy at West Point is accredited by the Middle States Commission on Higher Education.

The curriculum of the West Point Academic Program has evolved significantly from the initial focus on ‘moral, mechanical, geometrical and physical rules’. Today the academic curriculum provides a broad-based liberal arts education requiring all cadets to take courses in math, science, engineering, the humanities and social sciences. The curriculum is designed so that cadets can achieve this overarching goal: “Graduates anticipate and respond effectively to the uncertainties of a changing technological, social, political, and economic world.”<sup>4</sup> Cadets receive this education through both a core program and a majors program. Cadets can major in any one of over 40 majors from such disciplines as history, economics, physics and mathematics to one of several engineering majors. Figure 1 provides an overview of the courses cadets take at West Point. To graduate a cadet must successfully pass at least 40 academic courses of three-credit hours or more. In addition to these a cadet must pass several challenging physical education and military sciences courses. Of these 40 academic courses 30 are considered ‘core’ or required courses. In Figure 1 the green shaded boxes contain the core courses in math and the physical sciences. The blue boxes are the core courses in the humanities and social sciences. The red

boxes are the three core engineering courses, which cadets who are not engineering majors take in addition to their electives for their major program of study. The tan boxes are placeholders for the courses that cadets take in their major. Each major contains at least one integrative experience course that serves as the culmination of the cadet’s academic experience. For the engineering majors this is the Capstone course(s). Most of the engineering and computer science major programs are accredited by ABET. Cadets majoring in ABET-accredited engineering programs have to take at least 44 courses in order to meet the required hours for math, basic science and engineering topics since cadets take such a large load of core courses in the humanities and social sciences. Cadets may also graduate with honors if they meet certain grade point average and curriculum objectives. The overall academic curriculum prepares cadets well to ‘respond effectively to the uncertainties of a changing world’.

Freshman Year	1 <sup>st</sup> Semester	Discrete Dynamic Systems	Chemistry	Psychology	History	English Composition	
	2 <sup>nd</sup> Semester	Calculus I	Chemistry	Information Technology 1	History	English Literature	
Sophomore Year	1 <sup>st</sup> Semester	Calculus II	Physics	Philosophy	Political Science	Foreign Language	
	2 <sup>nd</sup> Semester	Probability & Stats	Physics	Physical Geography	Economics	Foreign Language	
Junior Year	1 <sup>st</sup> Semester	Engineering Sequence 1	Information Technology 2	Elective For Lang	International Relations	Leadership	Elective for Honors
	2 <sup>nd</sup> Semester	Engineering Sequence 2	Elective For Lang	Elective	Elective	Advanced Composition	Elective for Honors
Senior Year	1 <sup>st</sup> Semester	Engineering Sequence 3	Elective	Elective	Law	History of Military Art	
	2 <sup>nd</sup> Semester	Elective	Elective	Integrative Experience	Elective	History of Military Art	

Figure 1. The Academic Course Schedule at West Point

### The Systems Engineering Department

The West Point Academic Program is organized in and run by thirteen departments. Several topical research centers of excellence also exist to enhance the educational experience for cadets. The Department of Systems Engineering is the newest at West Point having been established in 1989. The mission of the department is *to educate cadets in Systems Engineering and related disciplines and inspire them to a career of service as professional officers who are prepared to identify opportunities and define problems, develop alternatives, make decisions and implement highly valued integrated system solutions to the complex problems facing our Army and Nation.* Since the founding of the department we have remained focused on four main priorities through which we accomplish our mission:

- cadet education;

- faculty growth and development;
- remaining linked to the industry we serve - the Army; and
- integrating state-of-the-art computer and information technology into the education process.<sup>5</sup>

Remaining focused on these priorities over time has enabled the department to make both cadets and faculty better leaders, problem solvers, communicators, technologists and team players. These are essential traits for high performing Army officers.

The department offers cadets several majors from which to choose. The Systems Engineering major educates cadets in designing integrated solutions to complex problems. The Engineering Management major develops cadets as professionals who provide engineering solutions to management and leadership problems. Both of these programs are accredited by the Engineering Accreditation Commission of ABET with the last re-accreditation visit occurring in 2008. The department offers a major in Systems Management that educates cadets as decision makers for a technological world. Cadets can also major in Operations Research where they take about ½ of their course work through the Mathematical Sciences department and ½ through Systems Engineering. The department also offers a three-course sequence in Systems Engineering for cadets that major in non-engineering disciplines. The disciplines offered by the department are very popular with cadets as we maintain a multi-disciplinary approach to their education that emphasizes solving real-world problems for real-world decision makers.

The department applies a general learning model for each of the majors and core engineering sequence as depicted in Figure 2.

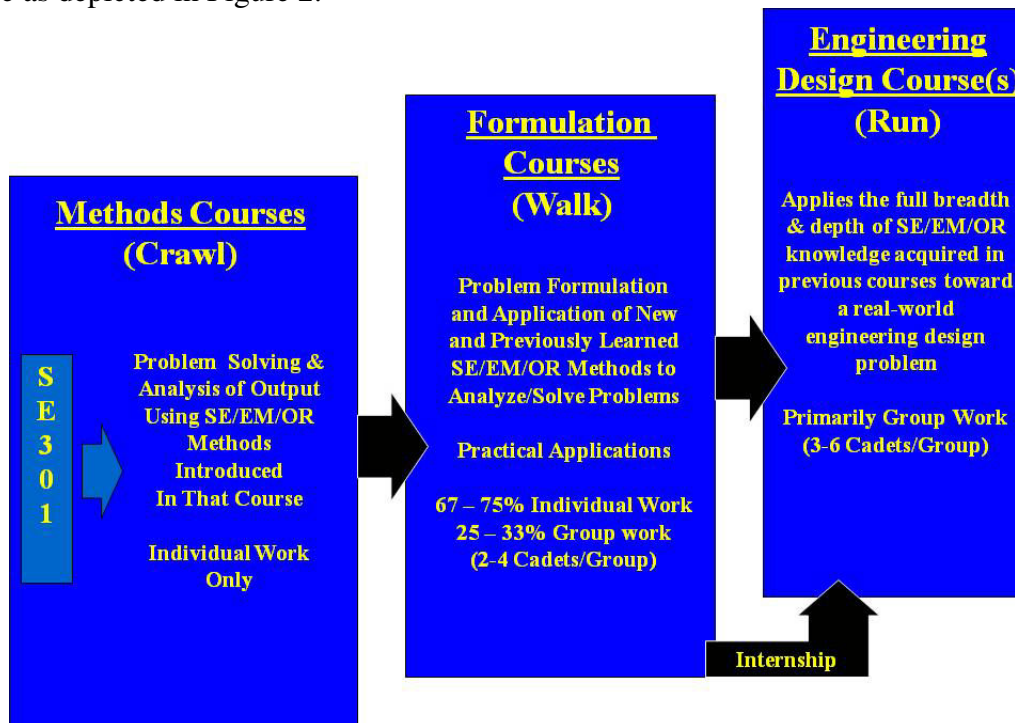


Figure 2. Learning Model for Majors in the Department of Systems Engineering

Cadets enrolled in all of the major programs start in the cornerstone course, SE301, which is titled Fundamentals of Engineering Design and Systems Management. Through this course cadets are grounded in our Systems Engineering thought and problem solving process, which we call the Systems Decision Process. This is explained further later in this paper. Cadets then take a series of methods courses in which they learn the basic tools and techniques necessary in the discipline. From there cadets matriculate to formulation courses in which they learn to apply and combine the tools and techniques from the methods courses in applied problem solving. Each cadet culminates their education in two Capstone engineering design courses (one for Systems Management majors) in which they take on a real-world problem from a real-world client applying the Systems Decision Process to design and develop a recommended systems solution. The clients typically are from military or other governmental agencies. When it is practical cadets may perform a three to four week internship with the client agency the summer before their senior year. This depends on the availability of cadets who are heavily engaged during the summer months in military training requirements. This learning model has remained valid and effective even as curriculum has changed as necessitated by our assessment processes.

### The Systems Decision Process

Over the years the department has evolved its Systems Engineering education to meet the needs of its students and constituencies. Recently the senior faculty of the department assimilated years of institutional knowledge and authored a textbook, *Decision Making in Systems Engineering and Management*, which is targeted for undergraduate systems engineering education but also used in graduate programs around the country. One of the central tenets of the book is the description and development of the Systems Decision Process (SDP), which is the engineering thought and design process taught in the department. Figure 3 contains the graphical model of the SDP.<sup>6</sup>

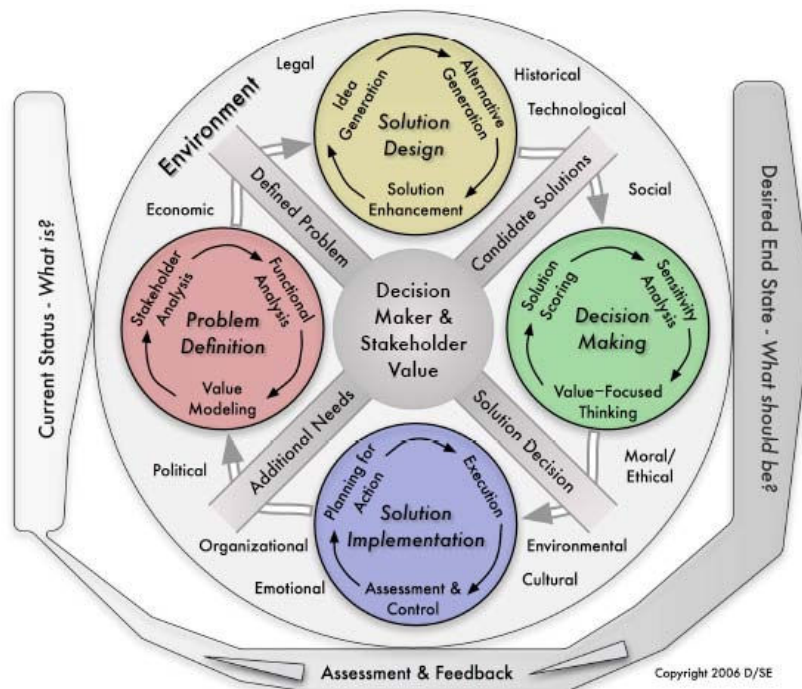


Figure 3. The Systems Decision Process (SDP)



A summary description of the SDP is appropriate here because the curriculum of the Systems Engineering major is designed to educate cadets to effectively apply this in solving real-world problems. Central to the SDP is a focus on ensuring that the values of stakeholders and decision makers remain prominent through the engineering design process. The SDP consists of four phases with each phase containing three primary tasks. The SDP is an iterative process with feedback loops and starts by gathering an understanding of the current problem domain through research and discussions with key decision makers.

During the problem definition phase engineers use stakeholder analysis techniques to elicit the needs, wants and desires of key stakeholders for a system solution to the problem. Through functional analysis the primary and supporting functions of the system are determined and the relationships between these are defined. In value modeling objectives and value measures are established by which alternative solutions will be evaluated later in the SDP. At the conclusion of the problem definition phase engineers should have a clearly defined problem statement, a set of constraints that the solution must meet and a value model for evaluating alternative solutions.

In the solution design phase various idea generation techniques are employed to start the development of creative and innovative solutions to the problem at hand. The most promising ideas are combined to generate a set of alternatives that are screened through the constraints determined during the problem definition phase. The result is a set of feasible alternatives, which are then enhanced. These enhanced solutions are then ready for analysis and evaluation.

The feasible alternative solutions are evaluated during the decision making phase. Various analytical methods are employed to study and score the alternative solutions on each of the value measures determined during the problem definition phase. This ensures that the alternative chosen remains true to meeting the most important values articulated by decision makers and stakeholders early in the process. After initial scoring rigorous sensitivity analysis allows engineers to determine those aspects of the remaining alternatives that add the most value in solving the decision maker's problem. These aspects are combined using a value-focused thinking process to refine the recommended alternative as appropriate. The results are presented to decision makers for approval.

The approved system solution is then implemented. Engineers have to plan for action and develop appropriate work breakdown structures in forming an engineering management plan. The systems solution is executed while employing appropriate quality control and measurement systems to evaluate the implementation plan. Throughout implementation the systems engineer assesses the progress and implements appropriate control measures to ensure the system continues to meet the intended objectives.

The SDP is contained in a bubble of environmental factors because systems engineering is a holistic, multi-disciplinary process. Engineers need to explicitly consider the organizational, economic, political, moral/ethical and social factors impacting the problem among other factors in order to develop the most effective systems solution.

## **The Systems Engineering Curriculum**

The Systems Engineering major program of study at West Point is one of the most popular majors because cadets understand the practical application of what they learn to life after West Point. The curriculum is designed to help cadets understand systems engineering as an interdisciplinary, life-cycle approach to the design, development, and deployment of complex systems, processes, or operations to meet the effective needs of users and stakeholder groups in a cost-effective, high-quality way. The program employs a full complement of assessment processes with the appropriate constituencies to keep the curriculum relevant. Figure 4 provides the current Systems Engineering program educational objectives and outcomes.

- Objective 1:** Produce graduates who apply systems thinking, systems engineering and systems decision making throughout a career of professional excellence and service to the nation as an officer in the United States Army.
- Outcome 1.1:** Define the problem, design solutions, make decisions, and implement the chosen engineering solution within a broad global and societal context.
- Outcome 1.2:** Act professionally and ethically as a leader of character within each stage of the system lifecycle.
- Objective 2:** Produce graduates who effectively lead interdisciplinary teams in Joint, Combined, inter-agency, and multicultural environments.
- Outcome 2.1:** Lead and work effectively as a contributing member of multidisciplinary systems engineering teams.
- Outcome 2.2:** Employ up-to-date techniques, skills, and engineering tools necessary for Army officers and systems engineering practice.
- Objective 3:** Produce graduates who use an interdisciplinary approach to complex systems engineering problems in uncertain future environments by converting stakeholder needs, want and desires into system functions and requirements.
- Outcome 3.1:** Identify and formulate a client's engineering problem and specify the client's actual needs using systems thinking, systems engineering and systems decision-making.
- Outcome 3.2:** Apply knowledge of contemporary stakeholder issues to systems decision making.
- Objective 4:** Produce graduates who develop and evaluate innovative, value-focused solutions by defining system performance measures to guide solution design, systems decision-making, and systems implementation throughout the system life-cycle.
- Outcome 4.1:** Define and measure system performance to guide solution design, systems decision-making and to validate that the design solution adds value and solves the defined problem.
- Outcome 4.2:** Design or re-engineer a system or process in order to develop alternatives that meet the needs of a the client within realistic environmental constraints such as cultural, historical, legal, moral/ethical, economic, environmental, organizational, emotional, social, political, and technological.
- Objective 5:** Produce graduates who manage uncertainty by applying their knowledge of mathematics, science, technology and engineering to develop, quantitatively evaluate, and implement effective and efficient solutions.
- Outcome 5.1:** Apply knowledge of mathematics, science, and engineering appropriate to Army officers and practicing systems engineers in order to develop, quantitatively evaluate, and implement effective and efficient solutions.
- Outcome 5.2:** Design and conduct systems experiments, including collecting, analyzing and interpreting data.
- Objective 6:** Produce graduates who communicate engineering solutions convincingly both orally and in writing to technical and non-technical audiences.
- Outcome 6.1:** Accurately, clearly, and concisely report findings, conclusions, and recommendations to the client in a manner that supports the client's decision.
- Objective 7:** Produce graduates who seek out and succeed in continued intellectual professional development in systems engineering and related fields.
- Outcome 7.1:** Demonstrate the skills necessary to support continued intellectual growth and learning for a career of professional excellence and service to the nation as an officer in the United States Army.

**Figure 4. Systems Engineering Program Educational Objectives and Outcomes**



Figure 4 represents an alignment of the program educational objectives with the educational outcomes. The program directors have ensured that courses in the program are aligned with outcomes so that what we teach adds value to the outcomes and objectives. This alignment continues down through courses to course objectives to lessons and lesson objectives. This keeps us teaching the right topics to support our graduates and their attainment of the program outcomes and objectives.

Cadets that major in Systems Engineering take their course work over their last five semesters. The curriculum is summarized in Figure 5.

	Term 1	Term 2	Term 3	Term 4	Term 5
1	SE301	SE375	SE370	SE402	SE403
2	MA206	SE387	SE388	EM411	EM420
3	Language course	Sub-Discipline Elective	Simulation Elective	Sub-Discipline Elective	Sub-Discipline Elective
4	PH202	CE300	ME311	EE301	LW403
5	EV203/ PY201	SS307	SE385	HI301	HI302
6	SS20X	EN302	PL300		SE400
<b>Required Courses for the SE Major</b> SE301: Foundations in Engineering Design and Systems Mgmt. SE370: Computer Aided Systems Engineering SE375: Statistics for Engineers SE385: Decision Analysis SE387: Deterministic Models SE388: Stochastic Models EM411: Project Management EM420: Production Operations Management SE402/3: Systems Design I / II (Capstone) SE400: Systems Engineering Seminar				<b>Sub-Disciplines</b> Human Factors Systems Information Systems Mathematical Systems Simulation Systems  <b>Simulation Electives</b> SE481: Systems Simulation SE485: Combat Simulation EM484: Dynamic Systems Analysis	
				<b>Engineering Principles Sequence</b> CE300: Fundamentals of Engineering Mechanics and Design ME311: Thermal-Fluid Systems I EE301: Fundamentals of Electrical Engineering	

**Figure 5. The Courses in the Systems Engineering Major**

The white blocks are courses that cadets take as part of the core program required at West Point. The yellow blocks represent the required courses in the major. The green blocks are general

engineering principles courses that enable cadets to interact with other engineering disciplines. Each cadet is required to take at least one simulation elective and the three offered by the department are listed in Figure 5. The blue blocks represent three courses that cadets take in a sub-discipline. The sub-disciplines allow cadets to explore a particular focus area for systems engineering in some depth. The available sub-disciplines and courses are provided in Figure 6.

<p><b><u>Human Factors Systems</u></b>  <u>Take the following:</u>            PL386 Experimental Psychology            and            PL485 Human Factors Engineering</p> <p><u>and either:*</u>            PL490 Engineering Psychology Design            or            PL488E Human Error</p>	<p><b><u>Mathematical Systems</u></b>  <u>Take the following:</u>            EM381 Engineering Economy  <u>and two of the following:*</u>            MA366 Vector Calculus and Intro to PDE            MA371 Linear Algebra            MA381 Nonlinear Optimization            MA386 Introduction to Numerical Analysis            MA391 Mathematical Modeling            MA476 Mathematical Statistics            MA481 Linear Optimization            MA488 Special Topics in Mathematics            MA490 Applied Probability from Math, Science and Engineering</p>
<p><b><u>Information Systems</u></b>  <u>Take the following:</u>            CS301 – Fundamentals of Computer Science            and            SE482 Command and Control Systems  <u>and one of the following:*</u>            CS350 Database Design and Implementation            IT382 Networked Systems Management            IT383 Human Information Interfacing            IT460 Information Warfare            CS482 Information Assurance            EV398 Geographic Information Systems</p>	<p><b><u>Simulation Systems</u></b>  <u>Take the following:</u>            Take one (or two) of the remaining two simulation electives offered in the Department of Systems Engineering  <u>and two (or one) of the following:*</u>            MS365 Campaigning: Operational Warfighting            MA476 Mathematical Statistics            EV398 Geographical Information Systems            The other simulation elective offered in DSE</p>

**Figure 6. The Sub-Disciplines of the Systems Engineering Program**

All the courses in the major are aligned with specific program educational outcomes and each serves a special role in educating cadets on the SDP. Cadets take SE301, Foundations of Engineering Design and Systems Management, as the cornerstone of their major. This course provides them an introduction to the SDP and they use it to solve a small scale problem so they become comfortable with this engineering design process. The required courses in the major align with program educational outcomes and are the methods and formulation courses shown in Figure 2 for the department learning model. These courses also emphasize specific phases of the SDP. For example, SE385 Decision Analysis provides cadets with advanced methods to use in the Decision Making phase. EM411, Project Management enables cadets to understand how to implement a systems solution.

Systems engineering majors culminate their education in two Capstone Design courses, SE402 and SE403, which are listed under the required electives in Figure 5. Cadets use the SDP to work on a new, significant problem with a real client who is connected to their future profession. Cadets work in teams of 4-5 for two semesters and most Capstones are led by Ph.D. faculty members. When appropriate cadets work on multi-disciplinary teams with cadets majoring in other engineering disciplines. For example currently systems engineering, engineering

management and mechanical engineering majors are working together on the design of a wind turbine that will lessen the impact of these structures on radar signals. The department concludes the Capstone Design experience in a conference at West Point during which cadets present their projects in different tracks to panels of judges who are distinguished individuals from academe, industry, government and the military. Members of the systems engineering board of advisors are among these judges so they can assess directly how well the cadets are meeting the program outcomes. The department invites other universities with undergraduate systems engineering programs to this conference and concludes the conference with an awards banquet. Over the past few years about six other universities sent student teams to compete in this conference.

### **The Assessment of our Program Educational Objectives and Outcomes**

In order to maintain the relevancy of our program to the needs of our constituents - the Nation, the Army, the Academy, the Systems Engineering community and the cadets themselves – we perform a comprehensive assessment and review process of how well we are meeting our program educational objectives and outcomes, which are provided in Figure 4. We maintain a board of advisors who represent our constituencies including distinguished individuals from academe, industry, military and other governmental agencies. This board of advisors meets twice annually to review our program and help ensure our program educational objectives (PEOs) and outcomes are appropriate. We provide an overview here of our assessment processes for both objectives and outcomes along with our current assessment of each. Details on specific assessment instruments are available from the authors.

To assess our program PEOs we use a combination of surveys administered to graduates and their supervisors along with focus groups of graduates. These are administered by both the university (West Point) and the Systems Engineering Program and target graduates at the 3-10 year point after graduation. We use this span of year groups in order to capture assessment data from former students who are currently working in both the military and outside the Army since all cadets incur a five year active duty service obligation upon graduation. West Point administers some of the survey instruments because the Army has institutional policies regarding the frequency, level and population targeted for surveys.

West Point conducts a triennial survey of graduates targeted specifically at those who graduated from ABET-accredited programs 5-7 years ago in order to get assessment information from alumni both in and outside the Army. This survey asks the respondents questions regarding their level of attainment of PEOs. West Point also administers an annual survey of graduates from a specific graduating class (normally the class that graduated 3 years prior to the survey) and an annual survey of their commanders, i.e. the supervisors of our graduates, from which we can get data specific to our majors that we can trace longitudinally. These surveys are linked directly to the USMA intellectual development domain goals that our PEOs are designed to support and the survey respondents can be identified according to their academic program of study; so these surveys are an excellent source of program-specific assessment data. The respondents for the commander's survey are supervisors who are providing an objective evaluation of our program graduates' performance in the field so this is a particularly powerful source of direct assessment data. These surveys also provide a direct measure of the continued intellectual development activities of our graduates, which can be used specifically in our assessment and evaluation of

PEO number five. We also use Army-level data on retention in the Army by our graduates, which is a direct indicator of the attainment of PEO number one. Specific questions from each of these surveys are linked to specific PEOs and the current and longitudinal data from these questions are used to inform the overall assessment of our PEOs.

The Triennial Survey and the annual USMA Graduates and Commanders surveys described above are valuable assessment tools for our program educational objectives. However in order to provide more timely and holistic assessment information regarding our PEOs we have recently instituted some additional PEO assessment instruments administered at the Program level. We have developed another annual assessment instrument that is targeted at a broader span of graduates than the triennial survey and the annual commanders and graduates surveys conducted by West Point. This was first administered in 2009. We also plan to annually conduct a focus group meeting at which we bring a group of our program’s graduates to West Point to obtain direct feedback on the degree to which they are attaining the PEOs. From these focus groups we will obtain supervisor information so we can get additional assessment data from their supervisors. We are implementing this focus group for the first time in 2010. These assessment instruments will reinforce the existing methods described above in helping us to periodically document and demonstrate the degree to which the objectives are attained.

Figure 7 provides a summary of the overall assessment of the Systems Engineering Program Educational Objectives. This overall assessment is completed by the Systems Engineering Program Director based on the results from the West Point Triennial Survey, the annual USMA Graduates Survey, the annual USMA Commanders Survey, and the initial results from the SE Graduates Survey - all described above. Additionally, the overall assessment is based on feedback from the Board of Advisors of the Systems Engineering program which includes members each of the constituency groups including the Nation, the Army, academia, and the Systems Engineering community.

<b>Systems Engineering Program Educational Objectives</b>	<b>Program Director’s Evaluation</b>
1. Produce graduates for a career of professional excellence and service to the Nation as an officer in the United States Army.	4.3
2. Produce graduates who effectively lead interdisciplinary teams in Joint, Combined, inter-agency, and multicultural environments.	4.4
3. Produce graduates who solve complex systems engineering problems in uncertain future environments.	4.5
4. Produce graduates who communicate engineering solutions convincingly both orally and in writing to technical and non-technical audiences.	4.4
5. Produce graduates who seek out and succeed in continued intellectual professional development in systems engineering and related fields.	4.5

**5 – Excellent, 4 – Very Good, 3 – Acceptable, 2 – Weak, 1 – Poor**

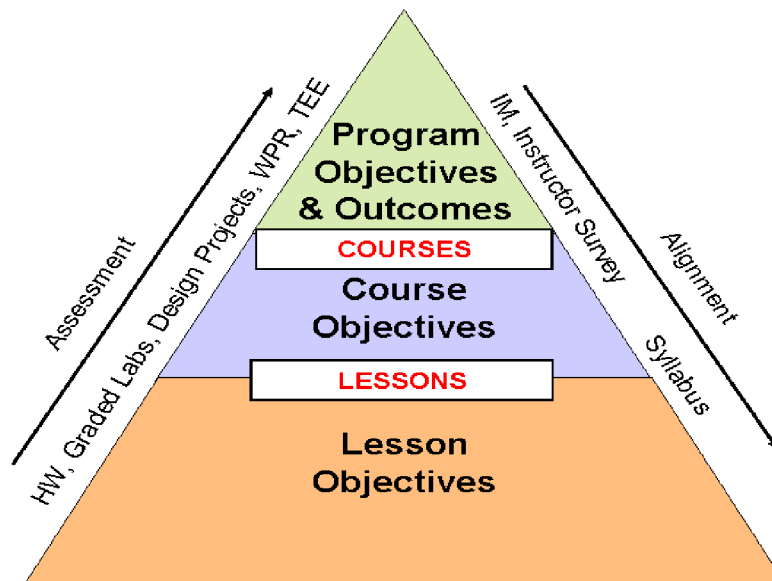
**Figure 7. Overall Assessment of Systems Engineering Program Educational Objectives**

For our assessment we defined the minimum acceptable level of achievement as an overall assessment of 3 out of 5 according to the following rubric: 5 is “Excellent”, 4 is “Very Good”, 3

is “Acceptable”, 2 is “Weak”, and 1 is “Poor”. The desired goal is for each of the PEO’s to score at least 4 out of 5. Based on this most recent evaluation, the Systems Engineering program successfully has attained its Program Educational Objectives.

In order to assess the attainment of our Systems Engineering program outcomes we use a combination of direct assessment, course assessment and program assessment instruments. This assessment starts with ensuring that our lesson and course objectives are properly aligned with our program outcomes, and that select evaluation methods in our courses are appropriate for use as direct assessment indicators of program outcomes. We have automated the collection of much of our outcomes assessment information on a web-based department internal ‘share point’ location. This facilitates collection and storage of the data to be used for informing current assessments and to enable longitudinal analysis. The details of our outcomes assessment methods are provided in a paper previously presented at an ASEE conference however we provide an overview here for readers.<sup>7</sup>

The alignment of our PEOs and program outcomes are illustrated in Figure 4. We accomplished this in concert with our board of advisors and this helps inform the structure of our Systems Engineering curriculum. We continue this alignment down from outcomes to course objectives to lesson objectives. This alignment is depicted in Figure 8, which is taken from the previous ASEE conference paper.<sup>7</sup>



**Figure 8. Program Alignment and Assessment Pyramid**

The pyramid in Figure 8 provides a visual representation of the alignment process. The development and assessment of our systems engineering curriculum is driven by our program educational objectives and outcomes. The courses and course objectives, and the lessons and the lesson objectives are properly aligned to ensure we are supporting all our program objectives and outcomes in the curricular design of the program. We ensure this alignment through the review of each of our course’s Instructor Memorandum (IM) and syllabus. On the assessment side of the pyramid we use cadet performance on specific portions of homework, graded labs, design projects, written partial reviews (WPRs, which is the term West Point uses for major course

exams), and term-end exams (TEEs, which are course final exams) as direct indicators of the level of attainment of program outcomes. The portions/questions of these specific graded events are identified by the Program Director who also tracks the collection of assessment data in our automated system. This direct assessment data is also provided in written course assessments completed at the end of each semester by the course director. The purpose of the direct assessment is to help the Program Director identify areas of strength and concern in our program's curriculum in preparing our students to meet the program outcomes.

We use performance criteria and scoring rubrics for each program outcome as the fundamental structure of our direct assessment process. For each program outcome we have established a set of performance criteria. To assess performance on each of the criterion we use scoring rubrics against which student performance can be evaluated. This structure is more fully explained in the previous ASEE conference paper. For illustrative purposes we provide an example rubric in Figure 9. This is one of the performance criteria for the program outcome *define and measure system performance to guide solution design, systems decision-making and to validate that the design solution adds value and solves the defined problem.*

<b>Performance Criteria:</b> Develop a value model that identifies and defines performance measures for the objectives of each system function.			
<b>Unsatisfactory</b>	<b>Developing</b>	<b>Satisfactory</b>	<b>Exemplary</b>
No value model developed.	Value model includes performance measures identified for most system functions.	Credible performance measures defined for each system function and objective.	Performance measures are defined that are aligned with and directly measure each of the system functions and objectives.

**Figure 9. Example Scoring Rubric**

We perform a complete evaluation of each cadet's performance in the two Capstone Design courses discussed earlier in this paper as a primary component of our program outcomes assessment process. These courses provide a framework to assess almost all of the performance criteria for each program outcome. Capstone course instructors evaluate each cadet's performance using rubrics for the performance criterion similar to that depicted in Figure 9. This assessment is completely automated so data is easily captured for storage and analysis. Since cadets take these courses in the senior year these outcome assessments provide an excellent indicator of the level of attainment close to graduation.

The Program Director combines the direct assessments discussed above from various courses and instructors with the information provided by course directors in the course assessments to develop an annual program assessment. The course assessments are meant to evaluate the effectiveness of the course content and pedagogy in enabling cadets to meet the stated course objectives. The course assessments include data and analysis from end-of-course surveys completed anonymously by cadets, which ask cadets to assess their level of understanding of course objectives among other questions. Since course objectives are aligned directly with certain program outcomes these course assessments provide another indicator of student

attainment of program outcomes. The program director formally documents the assessment process and analysis of the assessment data in an annual program assessment. In this document the program director uses the data from the multiple assessment instruments discussed here to arrive at an overall assessment of the cadets' level of attainment of program outcomes. The program director uses this information to identify strengths and areas of concern regarding the curricular design of the program or the pedagogy of specific courses, and to recommend changes to the program design. This program assessment is briefed to the Department Head and senior faculty, and the overall assessment of outcomes and recommended curricular design changes are also briefed to the West Point Dean on an annual basis. Figure 10 provides the latest overall assessment of program outcomes.

1. Define the problem, design solutions, make decisions, and implement the chosen engineering solution within a <b>broad global and societal context</b> .	<b>3.43</b>
2. <b>Act professionally and ethically</b> as a leader of character within each stage of the system lifecycle.	<b>3.36</b>
3. Lead and work effectively as a contributing member of <b>multidisciplinary systems engineering teams</b> .	<b>3.62</b>
4. Employ up-to-date <b>techniques, skills, and engineering tools</b> necessary for Army officers and systems engineering practice.	<b>3.41</b>
5. Identify and <b>formulate a client's engineering problem</b> and specify the client's actual needs using systems thinking, systems engineering and systems decision-making.	<b>3.60</b>
6. Apply knowledge of contemporary <b>stakeholder issues</b> to systems decision making.	<b>3.33</b>
7. Define and <b>measure system performance</b> to guide solution design, systems decision-making and to validate that the design solution adds value and solves the defined problem.	<b>3.24</b>
8. Design or re-engineer a system or process in order to <b>develop innovative alternatives</b> that meet the needs of the client within realistic environmental constraints such as cultural, historical, legal, moral/ethical, economic, environmental, organizational, emotional, social, political, and technological.	<b>3.24</b>
9. <b>Apply knowledge of mathematics, science, and engineering</b> appropriate to Army officers and practicing systems engineers in order to develop, quantitatively evaluate, and implement effective and efficient solutions.	<b>3.04</b>
10. Design and conduct systems <b>experiments</b> , including collecting, analyzing, and interpreting data.	<b>3.16</b>
11. Accurately, clearly, and concisely <b>report findings</b> , conclusions, and recommendations to the client in a manner that supports the client's decision.	<b>3.64</b>
12. Demonstrate the skills necessary to support <b>continued intellectual growth</b> and learning for a career of professional excellence and service to the nation as an officer in the United States Army.	<b>3.27</b>

Scale: 1=unsatisfactory, 2=developing, 3=satisfactory, 4=exemplary

**Figure 10. Current Assessment of the SE Program Outcomes**



## The Future of Systems Engineering at West Point

The West Point Systems Engineering curriculum benchmarks well to other leading undergraduate programs such as the University of Virginia, George Mason University and the University of Arizona. As we continuously improve our program we are refining the electives offered in the sub-disciplines. We are also considering the establishment of a financial engineering sub-discipline.

Systems engineering will continue to be a popular and growing discipline at West Point since the military needs systems engineers. Stories abound of defense acquisition programs that have quickly run behind schedule and over-budget due to a lack of solid systems engineering early in the acquisition process. Our officers need the ability to apply a systems thinking framework to the complex, interdisciplinary type problems they will face around the world, and a disciplined, engineering thought process for solving such problems. The Systems Engineering major at West Point that educates cadets in applying the Systems Decision Process provides our officer corps with these abilities.

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